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Abstract

The persistent underrepresentation of women in engineering continues to be a complex and difficult challenge. The interactions of young women and their parents during early, family-oriented engineering design experiences can provide girls with opportunities to express agency during an engineering activity, which can ultimately contribute to the development of sustained interest and self-efficacy in engineering. However, few studies have examined these parent-child interactions to date, and none have specifically focused on moments when girls express agency during an engineering design process. In this paper, we examine one such setting: a museum exhibit that engages visitors in engineering design activity. A qualitative content analysis was performed on transcripts from a total of 39 family groups videotaped at the exhibit, each involving a daughter between the ages of 5-12 and at least one parent. Qualitative codes describing the ways children expressed agency and led interactions with their parents included *directing, proposing design ideas, and asking questions*. Interestingly, the analysis also suggests that the young women in this study tended to direct their mothers more than their fathers. Although focused specifically on parent-child interactions, this study can inform both formal and informal engineering educators who engage young students in engineering activities.

Introduction

Ongoing efforts to recruit and retain women in STEM fields within the United States have had mixed success over the past three decades (Hill, Corbett, & St. Rose, 2010). While some areas of STEM, such as those connected to the life sciences and experimental psychology, have seen substantial increases in the percentages of women entering and completing undergraduate programs, other fields such as engineering, computer science, and physics have actually seen decreases over the past ten years in the overall percentage of women entering those programs (National Science Foundation, 2017).

Specifically within the field of engineering, there are several theories that attempt to shed light on the low numbers of women. Traditionally, engineering education researchers relied on the “chilly climate” and “leaky pipeline” metaphors to describe potential explanations for the dearth of women in engineering (Hoegh & Pawley, 2010). More recent studies, however, have begun to move away from these models, recognizing the need for a more complex, nuanced, and interconnected understanding of how and why women choose to enter or exit engineering pathways at different points in their lives (Matusovich, Streveler, & Miller, 2010; Sheppard, Atman, Stevens, et al., 2004; Trenor, Yu, Waight, et al., 2008).

To date, much of the research on recruiting and retaining women in engineering has focused on the retention of college-aged females in engineering majors and programs (Hill, Corbett, & St. Rose, 2010; Marra et al., 2009; Seymour, 1995; Seymour & Hewitt, 1997). While these studies at the undergraduate level are essential, an increased focus on the engineering perceptions and experiences of young women prior to attending college is necessary to more fully address the underrepresentation of women in engineering fields. Certainly over the past two decades exposure to engineering at the pre-college level has become increasingly common, particularly with the inclusion of engineering-focused practices within the Next Generation Science Standards and the rise in popularity of curriculum packages targeting pre-college learners such as *Engineering is Elementary* (eie.org) and *Project Lead the Way* (pltw.org). Moreover, early engineering and design experiences have long been a possibility for young learners outside the classroom, within informal learning environments such as museums, afterschool clubs, and libraries—and these opportunities only continue to increase, particularly with the rise of the Maker Movement (Svarovsky, 2014). Informal learning opportunities are often very social in nature, commonly engaging not only the young learner in an experience, but their peers, siblings, and parents as well (Feder, Shouse, & Lewenstein, 2009). Given the ways that parents in particular increasingly have been shown to impact career choices in STEM for women (Matusovich et al., 2010), examining these early engineering experiences within informal learning environments may lead to a greater understanding of how young women can begin to develop interest and confidence in fields like Engineering.

In this paper, we address this challenge by exploring one such engineering learning experience: an engineering exhibit within a large Midwestern science center, where parents and children engage collaboratively on an engineering design challenge. Specifically, this study investigates whether and how young women demonstrate agency during these design experiences, with the goal of advancing the understanding of what conditions can promote the engagement, confidence, and persistence of young women in engineering specifically and in STEM overall.

Background and Theoretical Framework

Persistence in STEM, Agency, and Design Practice

The construct of persistence in undergraduate STEM programs has been explored in multiple disciplines. For example, a comparative study following seven women showed the complexity of STEM persistence in the male-dominated STEM fields, finding that ways of persisting vary from situation to situation and that there is not a single, universal solution that women pursue to persist in these fields (Hughes, 2011). Another study found that factors related to successfully increasing persistence for students in STEM fields were to involve them in the "doing" of STEM, help them to create a "growth mindset," build their STEM identity, and foster a sense of belonging in the STEM community through a climate that favors peer interaction (Metevier et al., 2015). This work on persistence draws on several bodies of literature, as evidenced by the persistence framework advanced by Graham and colleagues that links persistence to learning theory, confidence, and motivational theory, and theories of identity development (Graham, Frederick, Byars-Winston, et al., 2013). However, while many studies have examined persistence at the undergraduate level, fewer studies have been conducted on persistence in STEM for pre-college students. Unlike at the undergraduate level, where persistence can be measured by the extent to which college students enter, stay in, and complete specific degree programs, studies of persistence at the pre-college level often focus on exploring the factors and conditions that lead to STEM-related motivation, achievement, and identity development (Banks, McQuater, & Hubbard, 1978; Calabrese Barton & Tan, 2010; Singh, Granville, & Dika, 2002).

One construct that has been helpful in discussions of STEM persistence at the pre-college level is the idea of *agency*. Drawing on the empowerment and agency indicators identified by Ibrahim and Alkire (2007), the definition of agency in this study is articulated as an individual's ability to assert control or choice within a given interaction. Developing a sense of agency around a particular topic has been shown to be connected to positive identity development and increased self-efficacy in a range of domains, including STEM (see, for example, Calabrese Barton & Tan, 2010, and Carlone, 2004). In some ways, the nature of engineering design may be a particularly fruitful context to explore opportunities for the expression of agency, given the structure of engineering as a discipline and the types of practices involved with the engineering design process. Engineering design is generally oriented toward creating a solution to meet or exceed a set of design goals, often under specific constraints (Crismond & Adams, 2012). During the engineering design process, an engineer demonstrates agency throughout, such as when advancing a particular design idea, making a decision about a type of material to use or the placement of a particular structure, or choosing to prioritize certain design constraints in response to client need (Dym et al., 2009). The nature of engineering design activities may afford young learners several opportunities to express agency by asserting their own ideas and decisions around the specific design being developed in the activity.

Expectancy-Value Theory and Persistence in STEM

Of course, engaging in engineering and design activities rarely happens in isolation, and therefore the broader contexts in which pre-college learners encounter and potentially develop persistence in engineering should be considered. A useful tool for examining these ideas is the *expectancy-value theory* (Wigfield & Eccles, 2000), which suggests that young people make choices about their careers by considering how successful they believe they will be at a given profession as well as how much they care about that profession. The creation of an expectancy-value model for a given context further highlights the connection between expectancies, values, and motivation, particularly around constructs of *performance, effort, and persistence* (Wigfield & Eccles, 2000). In other words, the alignment between what people believe they can do, what they value and are interested in doing, and their choices about what to do all come together to impact decision making and persistence in a given course of action—and in particular decisions about careers and college choices (Eccles, 2005; Eccles, Barber, & Josefowicz, 1999). A recent study applied the expectancy-value theory to their discussion of the impact of adolescent girls' experiences and beliefs on their mathematics and science motivation (Leaper, Farkas, & Brown, 2012). The study examined social and personal factors and how they relate to girls' motivation in the subjects of mathematics and science in comparison to the subject of English/language arts. The social factors they examined were the perceived support in mathematics and science from parents and peers, while the personal factors were gender identity and attitudes as well as exposure to feminism. Overall, they found that for adolescent girls their mathematics and science motivation was influenced by mother and peer mathematics and science support, as well as exposure to feminist and gender-egalitarian beliefs (Leaper et al., 2012).

The Role of Parents in Persistence in STEM

As illustrated by the study by Leaper and colleagues described above, parents have been shown to play a crucial role in children's achievement. One study investigating the effects of parents on their child's achievement found that parents' motivational practices positively influence their children's achievement in mathematics regarding where they start in seventh grade and how much they learn through the twelfth grade (Ing, 2014). These motivational practices were also shown to have positive effects on the children's later STEM careers. However, not every type of parental motivational practice was shown to influence children's mathematics achievement or persistence; instead, only the "mathematics-specific, intrinsically focused parental motivational practices," as opposed to extrinsically-focused practices, resulted in significant influences on persistence and achievement in STEM careers (Ing, 2014). Overall, this study shows the positive impact parents can have on their child's achievement, specifically by their motivational practices.

Certainly, the role that parents play in STEM persistence is essential, but it seems that this is particularly the case within the field of engineering. Several studies have suggested that both girls and their parents often underestimate their abilities in STEM (Frome et al., 2006; Herbert & Stipek, 2005; Lloyd, Walsh, & Yailagh, 2005; Tenenbaum, 2009; Voyles & Williams, 2004), which can lead to inaccurate beliefs about the likelihood of success within engineering fields. On the other hand, recent research has highlighted the crucial part that parents play in women's decisions to enter an engineering field, with one study suggesting that female engineers are significantly more likely than male engineers to have an engineer as a parent (Mannon & Schreuders, 2007). Another study identifies parents as influential figures who contributed to the students' decisions to major in engineering (Matusovich et al., 2010). However, few studies have been done specifically on girls' interactions with their parents while engaging in engineering design activities (Cardella, Svarovsky, & Dorie, 2013; Dorie, Cardella, & Svarovsky, 2014, 2015; Svarovsky et al., 2017). Understanding how these types of interactions occur and how girls can begin to demonstrate signs of agency during these experiences can inform how adults in general engage young women in engineering activities in productive ways.

The Gender Research on Adult-child Discussions within Informal ENgineering environmenTs (GRADIENT) study investigates interactions between parents and young women during a range of engineering activities within the informal learning context of a science museum. In particular, the present analysis explores whether and how young girls express agency (Calabrese Barton & Tan, 2010) during collaborative engineering activities with a parent by asserting some level of control (Ibrahim & Alkire, 2007) during the interaction, such as leading portions of the activity with their parent. This study addresses the following research questions:

1) Do young women demonstrate agency (as demonstrated by leading interactions) during engineering activities with a parent?

2) If so, what are the most common ways that young women lead interactions, and what are the most common ways that parents respond?

3) What patterns or relationships, if any, appear between the different ways that young women lead interactions and the ways that parents respond?

4) What differences, if any, exist between the ways young women interact with their mothers and their fathers?

Method

Research Context

To address the research questions posed above, a subset of video data from the larger GRADIENT Study (Cardella et al., 2013; Dorie et al., 2014, 2015; Svarovsky et al., 2017) was acquired and analyzed. The analysis for this study focused on data collected at an exhibit called the Pneumatic Ball Run, as seen in Figures 1a and 1b below.

(a) (b)

Figure 1. The pneumatic ball run component, as part of the Engineering Studio exhibit.

This exhibit is a component within a larger area of the museum called the Engineering Studio, which includes several interactive exhibits that invite visitors to engage in design activities. The Pneumatic Ball Run presents visitors with the design challenge of getting a small ball from the "Start" position on the left side of the exhibit to the "Finish" position on the right side of the exhibit. Visitors can use any of the materials within the exhibit, including simple, hand-operated pneumatic pistons, ramps, and cardboard tubes, to build a system that moves the ball across the face of the exhibit. Interestingly, the "Finish" position is higher than the "Start" position, thus making the design challenge more difficult and requiring visitors to consider both the materials and sequencing of pistons to propel the ball to a greater height. The Pneumatic Ball Run provided an engaging and multi-faceted engineering design experience for visitors on the museum floor.

Description of Sample

Overall, the GRADIENT study focused specifically on exploring interactions between young women and their parents during engineering activities. A purposeful sampling technique recruiting families with a young female child on the museum floor was used throughout the study (Patton, 2002). The data collected for the broader GRADIENT study included an emphasis on family interactions for girls at two age levels: pre-school (ages 3-5) (Cardella et al., 2013; Dorie et al., 2014, 2015; Svarovsky et al., 2017), and elementary/middle. For this study, the analysis focused on analyzing the video data from the elementary/middle school girls and their families, with a total of 39 daughter-parent groups included. Families were recruited to participate as parent-child dyads; however, at times other family members—such as a second parent or additional siblings—were also present.

The videos analyzed for this study focused on female children engaging in the Pneumatic Ball Run with a parent. The female children ranged in age from 5 to 12, with median age of 10. In 20 cases, the primary parent participant in the study was male. Females were the primary parent participant in 13 cases, and 6 cases involved both parents. Group size varied from 2 to 6 people, with 19 cases involving parent-child dyads. The remaining 20 cases involved an additional parent or siblings during the design activity. Within this sample of 39 families, 10% of primary parent participants identified as African-American, 6% as Native American, 2% as Hispanic/Latino, 2% as Asian, and 78% as White/Caucasian. The remaining 2% identified as "Other race/ethnicity." This demographic distribution is typical of museum visitors, as described in field-wide studies (Farrell & Medvedeva, 2010).

Segmentation of Data

Interactions between the parent and child participating in the engineering design activity were videotaped and transcribed, with 39 cases provided for the current analysis. Although 49 cases were collected for the GRADIENT Study, 6 of these were identified as pilot cases used for developing data collection methods and training data collection staff and 4 videos were removed from the dataset because they were deemed unusable by the original research team. The remaining 39 videos and transcripts were examined initially to identify patterns in the interactions between parents and daughters. Focused on exploring moments of agency, our units of analysis for the study were comprised of "child-led interactions," which we defined as any verbal interaction that the daughter initiates with her parent(s). Operationally, these child-led interactions began with a question or statement that the child initiated, followed by a parent's response (or lack thereof). These units of analysis were then compiled and coded using Dedoose, an online qualitative analysis program. In addition, it should be noted that a parent's response to child-led interaction did not have to occur immediately following the child's catalyst remark. In some cases following a short period of quiet building the parent responded in regard to the aforementioned topic or question.

Description of Coding Schemes

Child-led Interactions Coding Protocol

Each turn of talk within the child-led interactions was coded inductively for different types of interaction. Initial ideas for coding these interactions built on earlier coding schemes developed in the GRADIENT study, which also focused on turn-of-talk level interactions between adults and children (Cardella et al., 2013; Dorie et al., 2014, 2015; Svarovsky et al., 2017). This process led to two sets of refined codes: one set that focused on what the young women were doing during the interactions they were leading, and the other on how the parent(s) were responding to the child. The Child Initiation codes describe the different ways children led interactions with their parents. These codes included *design idea promotion, direct, question, statement of problem, or other*, as described in Table 1. For clarity, it should be noted that throughout the transcription and analysis conducted for this work participants were labeled as "CF" for Child, Female; "AM" for Adult, Male; and "AF" as Adult, Female.

Table 1. Child initiation codes for pneumatic ball run child-led interactions

Child Code	Abbreviation	Definition	Example
Design Idea Promotion	DIP	Proposing an idea or suggestion for the ball run	CF: "Oh yeah, we could make it; we could just make it lower" (Case 37, 7:44)
Direct	D	Telling parents what to do or explaining how something works	CF: "Dad, you have to try to get it in there. And Dad, this can do this" (Case 16, 14:49)
Question – Child	QC	Asking a parent a question, such as for clarification or if the adult is ready to start a new trial	CF: "So, wait a minute, the goal is to get it here, right?" (Case 32, 1:51)
Statement of Problem	SP	Commenting on a problem with the design or a piece not working	CF: "Dad, it can't get to the finish line." (Case 33, 21:01)
Other – Child	OC	Any other comment such as encouragement	CF: "We can do this!" (Case 33, 17:20)

Parent Response Coding Protocol

The Parent Response codes describe the different ways that parents responded to their children during the child-led interactions. These codes included *agreement, question, explanation, suggestion, non-response, or other*, as described in Table 2.

Table 2. Parent response codes for pneumatic ball run child-led interactions

Parent Code	Abbreviation	Definition	Example
Agreement	AG	Agreeing with child's proposed idea/instructions or replying in the affirmative	CF: "Oh yeah, we could make it; we could just make it lower" AM: "Right" (Case 37, 7:47)
Question – Adult	QA	Asking child a question; however, if it is more explaining than a real question, it is coded as S	CF: "No, I need your help." AF: "Okay, what do you need?" (Case 15, 31:25)
Explanation	E	Explaining a design piece or concept to child or giving an answer to what child proposed	CF: "We should put that over there, maybe, so once it can make it over" AF: "We could. But if we put it here, it will lift it up a lot higher." (Case 41, 8:00)
Suggestion	S	Suggesting an idea or command to child	CF: "Okay. Are you ready?" AM: "Wait, you gotta start there though" (Case 37, 6:13)
Non-Response	NR	No verbal response or saying something unrelated	CF: "Dad, you have to try to get it in there. And Dad, this can do this" AM: [no verbal response] (Case 16, 14:49)
Other – Adult	OA	Any other statement such as praise, laughter, or disagreement	AM: "Yeah, I see what you're saying. Yeah so it… So there's not resistance? It's a great idea" (Case 38, 24:50)

Inter-rater Reliability

After the qualitative codes were identified and initially applied by a primary coder to 20% of the sample, a second researcher conducted an inter-rater reliability (IRR) analysis and achieved a percent agreement level of 90% for the established child codes and 92% for the established parent codes. Differences were resolved by discussing the discrepancies and refining code definitions. After the IRR process, the remaining units of analysis were coded by the primary coder with these child and parent codes in the online coding software program, Dedoose (available at Dedoose.com).

Data Analysis

Although this study is qualitative in nature, a small amount of quantitative correlational analysis was conducted to further explore potential patterns of relationships among variables. Once the coding process was completed, the data were exported into Excel and subsequently into SPSS, where a bivariate correlation matrix was generated to identify any statistically significant relationships between each of the child and parent codes. Theoretically meaningful correlations that were statistically significant—even if the strength of relationship was quite small—were explored further in the qualitative data, which provided additional insight into the nature of the interactions between young women and their parents within these contexts. To be clear, these correlations are only meant to further understand the qualitative patterns in the coded data. They are not intended to be predictive or broadly generalizable beyond the participants of this study (Shaffer & Serlin, 2004).

Results

Findings from the study are presented in four parts, with each part aligning with a particular Research Question.

Part One: Girls Lead Interactions with Parents during Engineering Activities

Research Question 1 asks whether girls demonstrate agency during family-based engineering activities. The data suggest that girls in fact do express agency when interacting with their parents during these experiences. Across the 39 cases examined, 5,798 of the 17,178 total turns of talk were identified as part of a child-led interaction, which translates to an overall percentage of 33.8% of all possible turn of talk segments. These identified child-led interactions then became the units of analysis for the subsequent coding of Child Initiation codes and the Parent Response codes discussed below.

The percentage of how many segments within each case that were identified as part of a child-led interaction varied, as shown in Figure 2. The majority of the cases had anywhere from 21% to 40% of the turns of talk coded as child-led interactions. Two had 10% or fewer interactions coded as child-led, whereas only one had more than 60% of the turns of talk coded as child-led interactions.

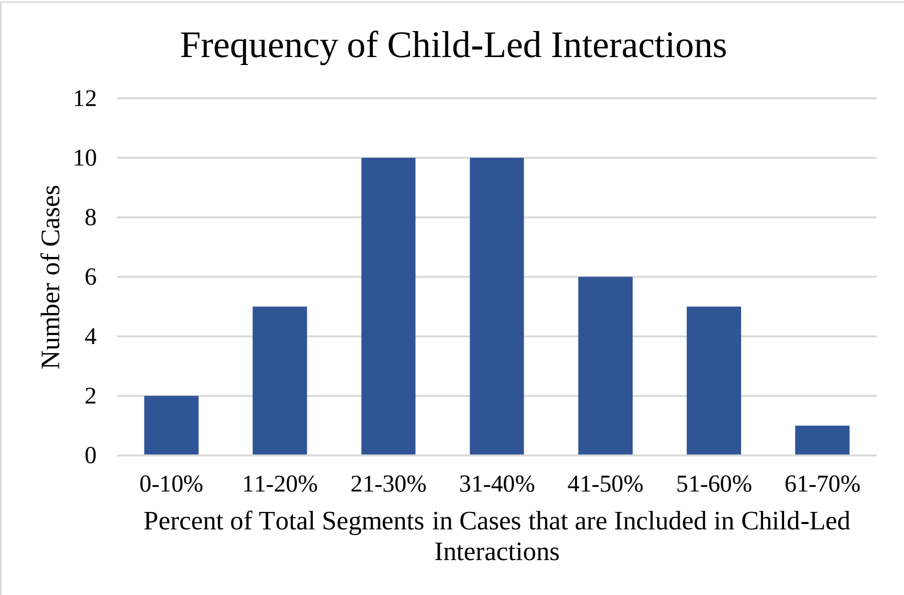

Figure 2. Frequency of child-led interactions

Part Two: Common Types of Child Initiation Moves and Parent Responses During Child-led Design Activities

Research Question 2 asks about the most common ways that young women led interactions with their parents as well as the most common ways that parents responded to their children. The Child Initiation codes described in the Methods section above reflect the most common ways that children tended to demonstrate agency during these exchanges. The distribution of the Child Initiation code frequencies can be seen in Figure 3. The “Direct” child code was the most frequent (36%) type of Child Initiation observed during the interactions. The second-most frequent is the “Design Idea Promotion” child code (17.9%), followed closely by the “Question” child code (17.7%). The “Statement of Problem” child code constitutes 14.2% of child-led interactions, and the “Other” child code had the smallest percentage (13.7%).

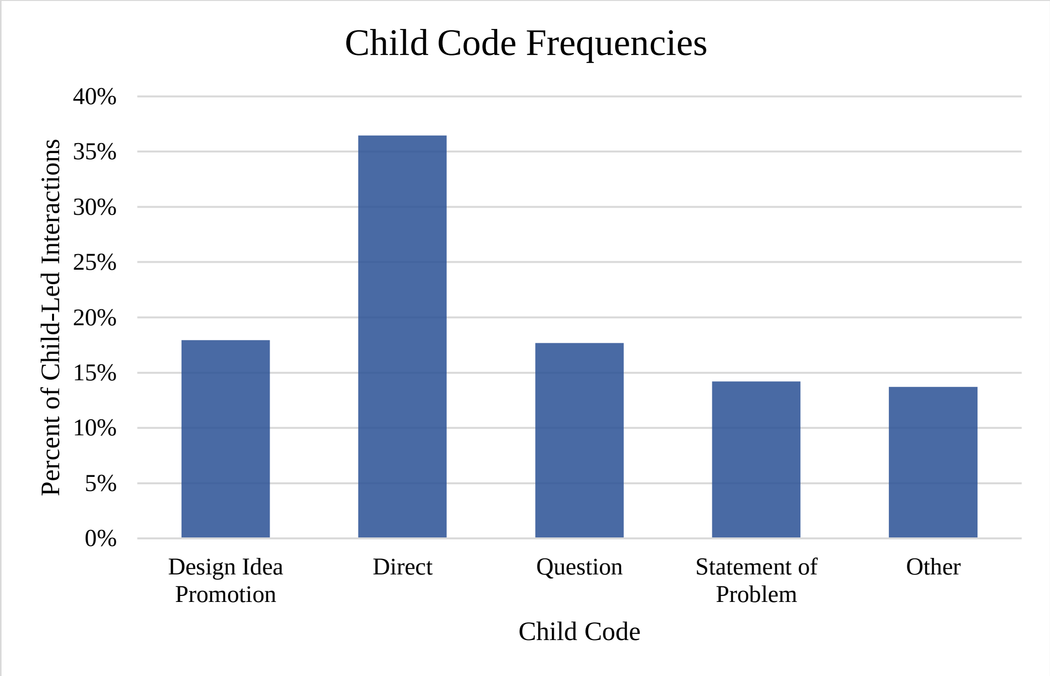

Figure 3. Distribution of the common ways young women led interactions with their parents

Similarly, the Parent Response codes listed in the Methods section above reflect the most ways that parents tended to respond to their daughters during these exchanges. The distribution of the Parent Responses code can be seen in Figure 4. The "Agreement" parent code was the most frequent (27.6%) type of Parent Response observed during the interactions, followed by the "Suggestion" code (20.4%), the "Question" parent code (15.9%), ”Other" (14.9%), "Explanation" (14.0%), and "Non-Response" (7.2%).

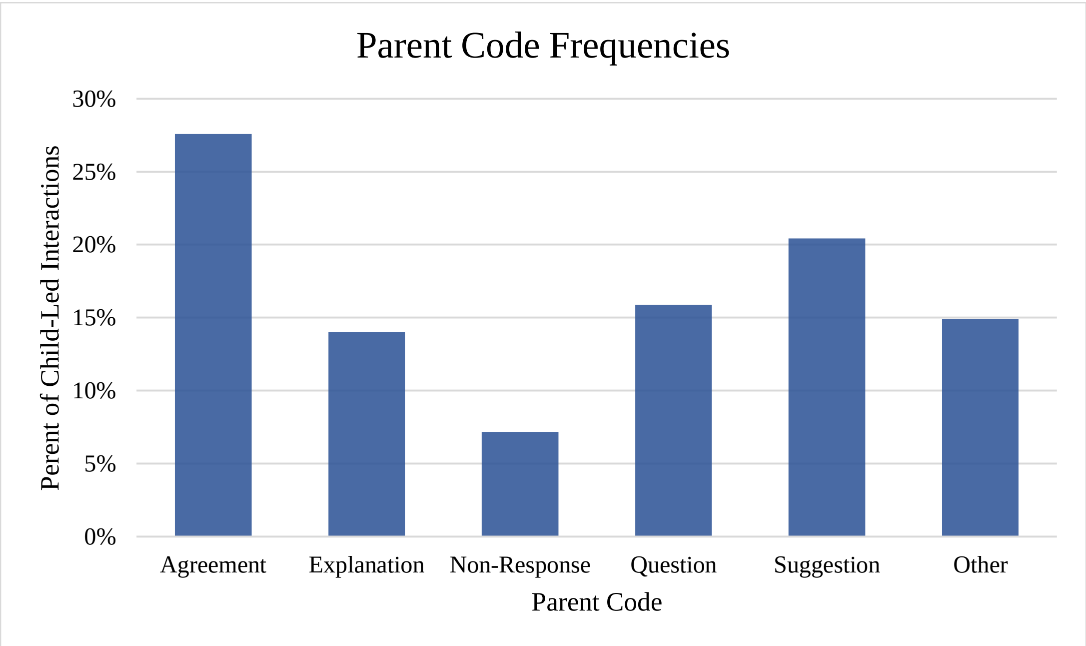

Figure 4. Distribution of the common ways parents responded during child-led interactions

These results from Parts One and Two suggest that girls in this study do in fact express agency by leading their parents in engineering design activities. Girls do this by initiating conversation primarily in the form of directing their parents and promoting design ideas. Parents in this study, in turn, generally respond to their daughters in agreement, but they also make suggestions, ask questions, and provide explanations. In the next section, we examine the relationships between the Child Initiation codes and the Parent Response codes.

Part Three: Patterns of Interaction between Children and Parents

Research Question 3 asks about the patterns or relationships between the ways that young women in this study led interactions with their parents and the ways in which their parents responded. To more clearly identify the patterns derived from the qualitative results, correlations between the Child Initiation codes and the Parent Response codes were estimated. From these analyses, four main interaction patterns are discussed.

Interaction Pattern #1: Parents tend to agree with a child's direction during design.

For the participants in this study, there is a link between children directing the decisions and activities during the design experience and the parent agreeing with the child, as seen in a small positive correlation between the "Direct" code for children and the "Agreement" code for parents (r=0.116, p<0.01). For example, Excerpt 1 demonstrates an instance in which the child directs her father who responds in agreement. Speakers are abbreviated as "CF" for Child, Female; and "AM" for Adult, Male.

Excerpt 1: Case 47, 22:11-28

Code	**Transcript Segment**
Statement of Problem	CF: It just can't, it can't make that.
Suggestion	AM: You gotta go faster to get over there.
Direct	CF: Cause this can't go any faster. See, just go like that.
Agreement	AM: Okay. Try it again.
Other, Child	CF: Oops. A little too fast.
Suggestion	AM: Oop, wrong way. Put it down again. Ha. Yeah, lower down a little bit and let it go again.

In Excerpt 1, the child describes a problem with the design, which is followed by a suggestion from her father that provides a solution to this problem. The daughter responds by directing her father, showing him what she wants him to do to fix the problem. Her father responds in agreement. The child expresses a difficulty to which the father responds by suggesting another way to improve the ball run design. This interaction shows a few exchanges, but the emphasis at this stage is the positive correlation evident by the father agreeing in response to his daughter's direction.

Interaction Pattern #2: Parents tend to respond to a child's statement of problem not by agreeing but by suggesting.

For the participants in this study, there is a small relationship between children verbalizing a problem with the design or describing a piece not working and the parent responding in a way other than simply agreeing with the child, as seen in a small negative correlation between "Statement of Problem" code for children and the "Agreement" code for parents (r=-0.051, p<0.01). When stating a problem, the child is trying to determine a solution, gain feedback, or receive another form of support; thus, agreement would not achieve this goal. An example of this is seen in Excerpt 2. Speakers are abbreviated as "CF" for Child, Female; and "AF" as Adult, Female.

Excerpt 2: Case 15, 23:01-23:21

Code	**Transcript Segment**
Statement of Problem	CF: I just need it, something to like escalate it a little more.
Suggestion	AF: Use this one.
Design Idea Promotion	CF: You know something, cause this it could like push it up, and then, to this, and then this could be a little more further up, and all these, they are like pushable ones, like go up.
Agreement	AF: I like it. Okay, try it.

In Excerpt 2, the child begins by stating a problem with one of the components of the ball run. She recognizes that she needs a piece to help the ball "escalate" more. The mother suggests a design piece to her daughter, which shows another trend observed that parents tend to give suggestions to their daughters when they state a problem, as seen in the small positive correlation between the "Statement of Problem" child code and the "Suggestion" parent code (r=0.047, p<0.05). The mother's suggestion encourages the daughter to continue working, and it even may have sparked the next design idea the daughter mentions, to which her mother agrees. With the help of suggestions from her parent, the child in Excerpt 2 is eventually able to reason through this current obstacle and eventually goes on to complete this segment of the ball run.

Interaction Pattern #3: Children's questions tend to be followed by parent explanations.

For the participants in this study, there is a relationship between children's questions of clarification to be followed by parents' explanations, as evident by the small positive correlation between "Question" child code and "Explanation" parent code (r=0.110, p<0.01). This is not entirely surprising, considering that when a child asks a question requesting either advice or instruction the expected response is an explanation from a parent, perhaps to give information about a concept. Excerpt 3 shows an instance where parent explanations followed a child's questions. Speakers are abbreviated as "CF" for Child, Female; and "AF" as Adult, Female.

Excerpt 3: Case 16, 1:58-3:14

Code	**Transcript Segment**
Question, Child	CF: Mom, where's the other one?
Explanation	AF: You don't want your ball to get caught here. So you gotta have it at the very end.
Question, Child	CF: Almost there. What's this?
Explanation	AF: This one, it's a...See how that goes like that? So you could have it flip over and go into the...You might want to move it over. Or the…
Question, Child	CF: Do we just like test it out quick, or something?
Non-Response	AF: [no response]
Question, Child	CF: How does it go up? Oh.
Explanation	AF: Oh, it doesn't go anywhere. So you gotta go what?
Direct	CF: Does it go any...down…
Question, Adult	AF: Okay. Then what's gonna happen to that one?
Direct	CF: This one has to go up. This one has to go…
Suggestion	AF: So you're gonna bring it down.
Question, Child	CF: Move it down. But then how's it gonna get up to there?
Suggestion	AF: Well, then that's probably where you're gonna wanna use one of these.

In Excerpt 3, the child initiates the interaction by asking a question, which is followed by an explanation of the design process by the mother. The daughter then asks another clarifying question, to which her mother explains again, this time by showing her daughter how a specific building piece works. These exchanges foster a continually questioning dialogue on the daughter's part. The last part of this excerpt shows the parent offering a suggestion to the child's question. Sometimes, a parent's response contained elements of both explanation and suggestion, which indicates that these types of responses are both common for parents in response to their child's queries. There is a small relationship between a parent responding to a child's question in a way other than with a question, as evident by the significant negative correlation between "Question" child code and "Question" parent code (r=-0.049, p<0.01). This correlation suggests that the parents in this study responded in a variety of ways that helped continue the design process. By responding to her daughter's question with a suggestion, this mother was able to help her daughter continue to persist in this engineering activity.

Interaction Pattern #4: Parents tend to engage in helpful conversations about children's design ideas.

For the participants in this study, there is a relationship between children proposing an idea or suggestion relating to the design of the ball run and parents asking questions about these ideas, as seen in a significant positive correlation between "Design Idea Promotion" child code and "Question" parent code (r=0.073, p<0.01). Parents generally responded by asking for further clarification, thus allowing the child to develop her idea. As reported in the section above, another small relationship observed was parents responding in ways other than a question, as evident by the negative correlation between "Question" child code and "Question" parent code (r=-0.049, p<0.01). Excerpt 4 shows this pattern of parents engaging in helpful conversation by responding to their child's question in a way other than posing a question, thus sparking further design ideas. Speakers are abbreviated as "CF" for Child, Female; and "AM" for Adult, Male.

Excerpt 4: Case 41, 24:26-39

Code	**Transcript Segment**
Question, Child	CF: This more up?
Suggestion	AM: I think what we can do is with just what we have here, and just how you pushed the labyrinth. How you push the, you need to maybe push it faster or slower?
Design Idea Promotion	CF: Faster.
Agreement	AM: Faster, why don't we try that?

In Excerpt 4, the daughter asks her father a question, which he responds to by proposing a suggestion to help clarify her understanding. In her next statement, she demonstrates her comprehension by suggesting to go faster, which was initiated as a result of her father clarifying some concepts during his suggestion. In this case, the father not only responds with a helpful suggestion to his daughter's question, but in his response sets her up for success by guiding her to the correct answer: to make this specific segment of the ball run work, his daughter has to push the piston faster. This effective exchange of ideas was evident throughout this case as the daughter was continually engaged even when she was confused, which enabled her to persist with the help of her father.

The results above suggest that there are several patterns in the interactions between daughters and parents during family-based engineering activities for the participants in this study. Parents tend to agree with a child's direction during design, and, instead of responding to a child's statement of problem in agreement, they tend to reply with a suggestion. When children ask a question, parents tend to give an explanation, and parents also tend to engage in helpful conversations about children's design ideas. These interaction patterns suggest that in a range of different interactions during this exhibit experience, parents are able to support their daughters' ideas and respond to their questions, which can help the daughter to further persist in this engineering design activity.

Part Four: Differences based on Parent Gender

Research Question 4 asks about what differences, if any, exist between the ways young women interact with their mothers and their fathers while engaging in the engineering exhibit. To more clearly identify the patterns derived from the qualitative results, correlations were estimated between the Child Initiation codes, the Parent Response codes, and parent gender. From this analysis, four main interaction patterns are discussed.

Gender Difference #1: Children tend to direct their mothers more than their fathers.

One interesting pattern in the data was the relationship between the Child Initiation code of Directing and the gender of the parent. In this dataset, daughters tended to direct their mothers than their fathers, as seen by the small positive correlation between "Direct" child code and "Female" parent (r=0.070, p<0.01) and the small negative correlation between "Direct" child code and "Male" parent (r=-0.055, p<0.01). Excerpt 5 shows an example of a child directing her mother. Speakers are abbreviated as "CF" for Child, Female; and "AF" as Adult, Female.

Excerpt 5: Case 15, 25:45-26:15

Code	**Transcript Segment**
Statement of Problem	CF: Yeah, here too. It's too much…
Suggestion	AF: It stops there, you're gonna need to push it up there.
Other, Child	CF: Okay. I thought there's a pushy there.
Other, Adult	AF: No.
Question, Child	CF: There isn't?
Suggestion	AF: We will need a push right here.
Direct	CF: Put lower this.
Other, Adult	AF: That's a good idea.
Direct	CF: Hold that, pull that up.

Question, Adult	AF: Ready?
Direct	CF: Push it. Yeah it stops.
Question, Adult	AF: Down more?

In Excerpt 5, the child begins by stating a problem with one of the components of the ball run, to which her mother responds not by agreeing but by offering a suggestion to continue the dialogue. The daughter thinks aloud, which then leads to asking a question that results in her mother's suggestion to add a design piece. The daughter then directs her mother to put a certain design piece lower, an idea her mother praises. Next, the child directs her mother to pull a piece up. The final direction by the daughter is to push a certain design piece, to which the mother asks a clarifying question. In this example, the mother is receptive to her daughter's instructions, which leads to a dynamic interaction during this part of the assembly process.

Gender Difference #2: Children tend not to promote design ideas with their mothers.

Children in this study were less likely to promote their design ideas with their mothers, as seen by the small negative correlation between "Design Idea Promotion" child code and "Female" parent (r=-0.067, p<0.01). Following the first child-parent gender relationship above, it seems puzzling that, although children direct their mothers more than their fathers, children are less likely to promote or advance their own design ideas with their mothers. This suggests that in this study there may be something different in the environment that affected how a daughter felt she could direct her parent. Excerpt 6 shows several instances of a child promoting her ideas when paired with her father. Speakers are abbreviated as "CF" for Child, Female; and "AM" for Adult, Male.

Excerpt 6: Case 24, 2:21-3:06

Code	**Transcript Segment**
Direct	CF: That's magnetic.
Agreement	AM: Yeah. How does that work?
Direct	CF: That's a strong magnet.
Suggestion	AM: Maybe we could try to get it. Whoops!
Design Idea Promotion	CF: Like that.
Agreement	AM: Like that.
Design Idea Promotion	CF: Then we could use this some…
Suggestion	AM: And then use something like that to bump the ball up?
Design Idea Promotion	CF: No. Then the ball couldn't get through if we used that. I just found something out that might help us.
Question, Adult	AM: What happens? Yeah.
Design Idea Promotion	CF: Wait a minute, I've got an idea.
Question, Adult	AM: What do you think? So, maybe we can put. See how that works?

Excerpt 6 is a dialogue between a child and her father that includes several moments of the child promoting her design idea. It begins with the child directing her father by her explanation of the magnetism of a design piece. The father responds first in agreement and then offers a suggestion. The daughter shows her father how to assemble a part of the ball run, to which her father agrees. This spurs the next few exchanges, which consist of another suggestion of an idea from the daughter and then a suggestion from the father. In response to his daughter's final two suggestions her father asks clarifying questions, remaining engaged with his daughter over the course of this entire segment. This excerpt also provides additional evidence to support the trend that parents in this study tended to agree with their children's directions.

Gender Difference #3: Mothers tend to agree.

Female parents in this study were more likely to agree to the child's statement or question, as evident by the significant positive correlation between "Agreement" parent code and "Female" parent (r=0.080, p<0.01). Excerpt 7 shows an instance where a mother agrees with her daughter. Speakers are abbreviated as "CF" for Child, Female; and "AF" for Adult, Female.

Excerpt 7: Case 26, 8:30-9:03

Code	**Transcript Segment**
Question, Child	CF: Okay, so how would that go through?
Suggestion	AF: Well try it.
Direct	CF: It’s gonna go down. Okay.
Agreement	AF: Yeah, go.
Statement of Problem	CF: What? Yep, but I won’t go over.
Suggestion	AF: If so, get ready, you can wait the ball. Stop. There you go. Now let’s just finish on this side.
Question, Child	CF: Oh, will it go this way?
Explanation	AF: No, cause it doesn’t have a main on that side. So you just use these.

This excerpt begins with a query from the child about how the ball run would work, to which her mother responds with a suggestion to try and see. In the second child-led interaction, the daughter directs her mother by explaining what will happen next—specifically, that the ball will go down—to which the mother agrees. After the mother’s agreement, the dialogue continues with problem-solving and suggestions back and forth. The end of this excerpt also further supports the previously-stated trend that parents offer explanations to their daughter’s questions.

Gender Difference #4: Fathers tend to respond more to their daughters.

Fathers in this study were less likely to provide a non-response to a statement or question initiated by their daughters, as seen in the small negative correlation between “Non-Response” parent code and “Male” parents (r=-0.046, p<0.05). By being less likely to not respond, fathers created more opportunities for engagement with their daughters by some form of response. Excerpt 8 shows an example of a father playing a critical role in responding to his daughter’s ideas. Speakers are abbreviated as “CF” for Child, Female; and “AM” for Adult, Male.

Excerpt 8: Case 41, 7:45-8:00

Code	**Transcript Segment**
Design Idea Promotion	CF: Or maybe we should put this more right here, so can lift it up like nothing and can go up.
Question, Adult	AM: Say what?
Design Idea Promotion	CF: We should put that over there, maybe, so once it can make it over.
Suggestion	AM: We could. But if we put it here, it will lift it up a lot higher. So what we wanted to do, maybe what we’re gonna need to do is, uh, lower this side down so it rolls more into it. So the force of gravity gets the ball going, cause it kind of has to land like right into here.

In Excerpt 8, the daughter proposes a design idea, to which her father responds by asking her to repeat herself. After she clarifies her design idea, her father provides a suggestion that both explains to his daughter why her idea structurally will not work and also gives another option to solve this problem. The father in this case had the opportunity not to respond to his daughter, but instead he asked a clarifying question to continue to assist his daughter with the activity. This excerpt was one of the most prominent examples of the constructive role parents could play in their daughter’s learning and interest in the activity.

These findings suggest that for the participants in this study there is variation in the ways that female children engage with parents of different genders when engaged in engineering activities. Female children are more likely to direct their mothers than their fathers but less likely to promote their design idea with their mothers. Mothers are more likely to respond by agreeing with their daughters but less likely to respond by explaining. Fathers tend to respond more to their daughters. Further examination of these patterns can help shed light on the ways mothers and fathers can play a role in the development of engineering interest, identity, and agency in young women.

Discussion

This study found that interactions during family-based engineering activities can be productive learning experiences for girls to begin demonstrating early elements of persistence. The proportion of overall turns of talk coded as child-led interactions in Figure 2 shows that girls are leading interactions during design activities. When girls lead activities they are more likely to be interested in the activities, which can result in greater levels of persistence. The majority of the child-led interactions consisted of children directing their parents, but other patterns included children promoting their design ideas and asking questions. The majority of parents' responses were in agreement with their daughter, but parents also were observed to make a suggestion and ask a question. Several patterns also were discovered in the interactions between daughters and parents. For example, parents tend to agree with their child's directions and respond to their statements of a problem not by agreeing but by suggesting. Mothers were more likely to agree, but fathers were more likely to respond. Parents tend to provide explanations to children's questions and engage in helpful conversations about their child's design ideas. A striking difference was discovered between the ways girls interact with their mothers and fathers; girls were significantly more likely to direct their mothers than their fathers. They were also less likely to promote their design ideas with their mothers.

These findings suggest that there might be connections between the ways that parents engage with their daughters during engineering design activities and the ways that girls exhibit elements of persistence through demonstrating agency in STEM activities. This study shows a strong link between children directing and parents agreeing. In Excerpt 1, the daughter directs her father by showing him what to do to fix a problem. He responds in agreement but in a way that sets up further dialogue, thus fostering effective communication. By agreeing and then later also providing a helpful suggestion, the father plays a role in his daughter's continuation of the activity and ultimately her achievement in successfully completing the activity. Parents' motivational practices can positively influence their children's achievement and parents' intrinsic motivational practices can even result in higher persistence in STEM careers for their children (Ing, 2014). As expectancy-value theory emphasizes, individuals' motivation, such as how much they value an activity or how they think they will do, has a large impact on their persistence and performance (Wigfield & Eccles, 2000). Because the father was agreeable in Excerpt 1, he provided a positive response to his daughter's leadership during this engineering activity, which may contribute to her overall confidence and self-efficacy in engaging with these types of engineering design activities.

These findings support previous research showing that parents can be positive influences on student motivation (Farmer, 1985). The positive effect of parental support is seen by the trend that when a child mentions a problem, parents usually respond in a productive way instead of simply agreeing with their child. As seen in Excerpt 5, in response to the child's statement of a problem, the mother provides a suggestion to her daughter that initiates further dialogue. The result was collaborative problem-solving by the mother and daughter, which led to eventual completion of that immediate segment of the ball run. For adolescent girls in particular, their math and science motivation is influenced by mothers and by peer math and science support (Leaper et al., 2012). In this example, the daughter's motivation to continue to persist in the activity is sparked by her mother's suggestion, which acts as a springboard for further discussion. In this case the mother's support has lasting effects, as seen by the daughter later directing her mother and showing leadership in the activity. As a result of parental support positive consequences are seen later in the activity. This suggests that parents can encourage their children's later success and ownership of an activity, which has been shown through expectancy-value theory to impact their persistence and performance (Wigfield & Eccles, 2000). Research showing that teachers can be positive influences on student motivation suggests that the findings of this study may also apply to how teachers and students interact in a classroom (Farmer, 1985).

These results also emphasize the impact of incorporating gender-specific strategies in these engineering design activities. Strong verbal tendency is commonly associated with females. Studies have shown that teachers are aware of the strong verbal tendencies of females and thus try to incorporate this verbal component into science by asking girls higher-level questions or incorporating verbal components in hands-on lab experiences (Subrahmanyan & Bozonie, 1996). Excerpt 3 is an example of an educationally-enriching dialogue between mother and daughter that demonstrates the efficacy of conversation in engineering design activities. The child initiates the interaction by asking a question to which her mother responds by explaining part of the design process. This leads to several more exchanges of dialogue, one of which includes the mother asking a thought-provoking question that challenges her daughter to think critically about how a certain piece will influence the design. By providing constructive responses, the mother creates an environment that fosters constructive conversation that leads to a continuation of the design process, despite the daughter's initial questions. Not only does the strong verbal communication between mother and daughter help provide a productive learning environment, but the hands-on aspect of this activity further strengthens the daughter's persistence.

Additional observations from the dataset suggest that these parent and child interactions might not always be in direct support of persistence. For example, in Case 12, despite no obvious external signs of frustration on the part of either participant, when the father asks his daughter if they want to try another activity she instantly agrees. Up until this point the daughter had been leading the activity, and they were working together without any major problems. This example shows a downside of what can happen if a parent does not feel the need to persist in the STEM activity and the child follows his lead. While this museum environment lends itself to the distraction of other activities, this case nonetheless shows the impact that parents' decisions not to persist can have on their impressionable children. In Case 12, the father and daughter did not seem as attached to the activity given that they were able to leave quickly and easily. There were other cases, however, where the parents had to ask several times for their daughter to be done with the activity. While these examples were positive in that the daughters were determined to persist, they also show the negative effect that parents can have when they are attempting to persuade their daughters to stop working. Case 31 even ended with the child in tears, as she was frustrated with both the activity and her father's insistence that she need to leave immediately to go home. Overall, while the majority of the correlations described above can have positive implications, larger themes seen in the videos depicted underlying challenges when parents are involved with their daughters' persistence.

Limitations, Implications, and Future Work

This study has multiple limitations. First of all, the scope of this study is limited by the sample of families who participated in the study. Parents who visit a science museum with their children may be of a similar demographic in terms of educational attainment or socioeconomic status (Farrell & Medvedeva, 2010), or they already may be more inclined to engage and collaborate with their children. Therefore, it is important to consider this bias when interpreting these findings. Second, there was not a closed system during the experimental data collection. The exhibit was in the middle of a busy museum floor, which allowed for some interaction with people outside the scope of the study. Siblings were also a distraction, as well as parents who entered midway through the design project. These added family members were not prevented from joining the original parent-child dyad since they could create more opportunities for family interactions. Finally, the lack of additional demographic data for the participants limits the types of analyses that can be done on this subset of data from the GRADIENT study. Additional information about the family, such as whether it is a single-parent household, the typical temperament and disposition of the parent and child, and general parenting styles and techniques used in the daily routines of family life, all could better inform the interpretation of these data analysis results.

Despite these limitations, our findings still have implications for potentially increasing the persistence of females in STEM. These results give us an initial picture of the specific ways daughters engage with their parents during a challenging engineering design activity, whether by directing, stating a problem, promoting a design idea, or questioning. The specific ways that parents respond to their daughters by agreeing, explaining, suggesting, questioning, or not responding also provided insight. These findings can be useful for both informal and formal educators, such as parents and teachers, as they continue to develop their understanding of how to foster environments where girls can lead interactions during STEM activities by being actively engaged and expressing agency. Since much of the research on persistence in STEM focuses on college-aged students, any teacher introducing engineering concepts to pre-college students would be able to draw upon this research to learn about productive ways to structure learning environments and practices to engage young women in developing confidence, interest, and self-efficacy during engineering activities. Parents might also be able to leverage these findings and engage their female children in authentic collaboration during family-based STEM activities, which might impact their daughter's ongoing development of motivation and persistence in STEM.

Future research on interactions during family-based engineering activities could focus on a variety of topics. A follow-up study could focus on exploring these patterns in a sample of parent-child dyads where all the children are boys, thus providing the comparison group that would allow researchers to identify patterns between the ways that fathers or mothers interact with their sons and then compare these patterns to those identified in this study. This shift in focus would allow for further knowledge of the dynamics between parents and their sons and daughters in an attempt to identify any similarities or differences between these child-parent interactions. In addition, further analysis of the variation in patterns based on time-on-task, the presence of siblings (both older and younger), and additional demographic information such as the occupations of the primary parent participant could also continue to refine the interpretations of these data and the findings of this study.

Using this same dataset, different codes during analysis could be applied to answer other research questions such as how children respond when faced with a specific challenge in a design activity and what parents can do to prompt a productive response. This study focused on the expression of agency through primarily verbal communications between children and parents, but another topic of interest could be to examine nonverbal cues. Identifying what actions girls take when they come across a challenging part of the activity could provide further insight into ways parents can help foster persistence through their actions as well as words. The context of this study could be expanded to include a different engineering activity in this same museum but could also be translated to other environments such as a classroom. All of these future directions could lead to positive insights into the effects of environments and adults on young children's persistence in STEM activities, which could have implications for the development of more productive learning environments and instructive practices for young STEM learners in the future.

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